

CHAPTER 15

GEOLOGICAL DISPOSAL DEEP UNDERGROUND A STUDY OF THE JAPANESE GEOLOGICAL ENVIRONMENT AND ITS STABILITY

Aiji Yamato

Power Reactor and Nuclear Fuel Development Corporation,
1-9-13 Akasaka, Minato-ku, Tokyo 107 Japan

15.1 INTRODUCTION

In order to demonstrate the scientific and technological safety of geological disposal in Japan, it is important to make an accurate assessment of the geological environment and to incorporate this knowledge into the performance assessment and R & D of disposal technology based on a realistic model of this environment. At present, surveys and studies are being conducted without specification of regions or rock types.

Geoscientific knowledge to date indicates that the geological environment deep underground is characterized by generic qualities found in all regions and other qualities, which are peculiar to a specific region. For an effective assessment of the Japanese geological environment, it is important to make a systematic collection of data on specific and generic regional characteristics that are relevant to geological disposal.

Based on their origin, rocks can be divided roughly into three groups, igneous, metamorphic, and sedimentary. Within these groups, various subdivisions are categorized by mineral/chemical components, grain size and texture, etc. However, from the viewpoint of groundwater flow and mass transport, which are pertinent to the performance assessment of geological disposal, the present characteristics of rocks have a greater significance than those at the time of their formation. These characteristics include physical and chemical qualities, the hydraulic structure of rocks deep underground, and the chemical properties of rock groundwater systems, such as the extent and rate of nuclide sorption. Based on this approach, it is possible to classify the rock formations in Japan into two groups: crystalline rocks (fractured media) and sedimentary rocks (porous media). Granitic and sedimentary rocks of the Neogene are widely distributed throughout Japan and can be taken as being rep-

resentative of the two groups defined above.

The Power Reactor and Nuclear Fuel Development Corporation (PNC) is promoting geological research with emphasis on present-day conditions. A new research division has been established to perform surveys and studies of the deep geological environment as a basis for research and development (R & D) programs on geological disposal.

This report outlines the R & D activities conducted so far, as well as future plans.

15.2 PURPOSE AND PROCEDURES OF RESEARCH AND DEVELOPMENT PROGRAMS

The purpose of geological research is to characterize the geological environment of Japan from the point of view of geological disposal, to construct models of geological structures and groundwater flow, to systematize available data, to make accurate and efficient assessments of the geological environment, and to develop practical technologies for analysis and evaluation purposes. The models and data obtained through such studies are applied in performance assessment and R & D programs.

Data on the flow and geochemical characteristics of groundwater, as well as on mass transport, are important in assessing the performance of the near-field and far-field in a geological disposal system. In near-field studies, it is essential to obtain accurate data on the hydraulic and geochemical characteristics of the bedrock adjacent to the engineered barrier system, including the excavation disturbed zone. For the far-field, on the other hand, data are required on the groundwater flow and mass transport characteristics of fracture and alteration zones over a wide region and on hydraulic

and chemical properties at the boundary between seawater and freshwater in coastal regions.

Since data on the deep geological environment must be as precise and reliable as possible from the viewpoint of geological disposal, it is therefore necessary to develop and improve the technologies used in surveys and measurements to ensure more efficient and detailed data acquisition. Equipment is being developed that will allow surveys of bedrock with very low permeability or under the high pressure and temperature conditions prevailing deep underground in order to advance studies of hydraulic and geochemical characteristics. At the same time, attention is being given to methods which are disturbance-free, i.e. they do not cause damage or upset the natural condition of the rock. For this purpose, efforts are being directed toward improving techniques of physical and drilling surveys as well as integrating various survey techniques.

A given geological environment is considered stable for the purpose of geological disposal if the formation, selected as being most appropriate, can maintain its required role for safe disposal despite the potential for changes in the environment. In order to assess the stability of a geological formation, it is necessary to ascertain potential changes in the environment brought about by various phenomena, as well as the extent of these changes. Predictive studies require analysis of data related to the occurrence and regularity of natural phenomena (extent, region, regularity, mechanism of occurrence, etc.) and identification of a pattern of regularity, if any.

Studies on the geological environment include compiling accumulated data and the most recent findings in related fields of science and engineering and applying the results of geological R & D at the Tono and Kamaishi mines. Cooperative studies with other countries advanced in the field of geological disposal also contribute to establishing investigation techniques and procedures for performance assessment.

15.3 CHARACTERISTICS OF GEOLOGICAL ENVIRONMENT AND CURRENT STATE OF KNOWLEDGE

Deep geological formations are generally characterized by extremely slow groundwater flow and a reducing chemical environment of neutral to slightly alkaline nature. As a result, it is unlikely that radionuclides within the waste will be significantly leached out; even if the

waste matrix does dissolve, the likelihood is that the escaping nuclides will either be sorbed onto clay minerals in the adjacent bedrock and fractures or will be precipitated. It is expected, therefore, that the migration of radionuclides will be even slower than the rate of groundwater flow.

Tests conducted on sedimentary rocks in the Tono region of Gifu Prefecture indicated the hydraulic conductivity to be approximately 10^{-8} m/s to 10^{-10} m/s and the oxidation-reduction potential to be low at -300 mV for groundwater at 160 m depth. In the case of the Tono uranium deposit, one characteristic of the geological environment which is evident is that no major migration of uranium has occurred in the past 10^5 years.

The deep geosphere also has the characteristic, compared to the ground surface, of not being readily affected by natural phenomena such as earthquakes, glaciation, weathering and erosion, or by human activities.

Earthquake observation in the gallery of the Kamaishi Mine indicated that the ground acceleration rate measured several hundred meters underground was approximately half that measured at the ground surface. Long-term observation of the pore pressure and chemical properties of groundwater has revealed no major change so far. Temporary changes are recorded at the time of an earthquake, but these are within the range of seasonal fluctuations (Shimizu, et. al., in press).

One of the natural phenomena considered to have a potential influence on the stability of the geological environment is the fault activity assumed to have occurred during the Quaternary. A survey of fault distributions indicates that there is a wide region without any faulting and, even within regions where numerous faults are found, there are blocks of rock where no faults exist. Igneous activity occurring in the Japanese archipelago is likely to be related to the location and depth of plate subduction in the vicinity, but there has been no major change in the past 12 million years. Periods of glaciation and sea-level changes are global phenomena which have been repeating in cycles of approximately 10^5 years for the past 7×10^5 years. An accurate understanding of regional characteristics, regularities and cycles in natural phenomena, allows the stability of the geological environment to be assessed reliably.

15.4 PRESENT RESEARCH AND DEVELOPMENT

Of the geological research and development currently

underway, a report is presented here on the present studies of geological formations and on R & D procedures relating to assessing long-term safety.

15.4.1 Investigations Conducted at and Around the Tono Mine

The Tono Mine is a uranium mine situated in the Tono region of Gifu Prefecture. The region around the Tono Mine is formed basically of granite, covered with

Neogene sedimentary rock (Fig. 15.1). In this region, an enormous amount of geological information is being accumulated through uranium prospecting and academic research. The shaft and gallery leading to the mine allow access to sedimentary rocks, including uranium deposits, over one hundred meters underground. Surveys conducted in this region include the hydrology and geochemistry of groundwater, mass transport by groundwater and the effect of excavating galleries on the geological environment (Yusa, et. al., 1992).

Figure 15.1. Geological and Location Maps of the Tono Mine Region.

The hydrological research being conducted at present includes accumulation of reliable hydraulic data down to a depth of 500 m below ground surface, construction of a hydrogeological model based on survey results, consideration of methods for predicting groundwater flow and evaluation and verification of the groundwater flow model (Fig. 15.2). The results of permeability investigations conducted on Neogene sedimentary rocks and granites in the Tono region indicated that the

hydraulic conductivity of sedimentary rocks is higher for coarse-grained formations. The value was approximately on the order of 10^{-8} m/s for medium to coarse sandstones. The hydraulic conductivity of granites is classified into two categories of high permeability (10^{-5} to 10^{-6} m/s) measured in the vicinity of open fractures and low permeability (10^{-8} to 10^{-11} m/s) measured in the unfractured rock mass and in fracture zones filled with clay minerals.

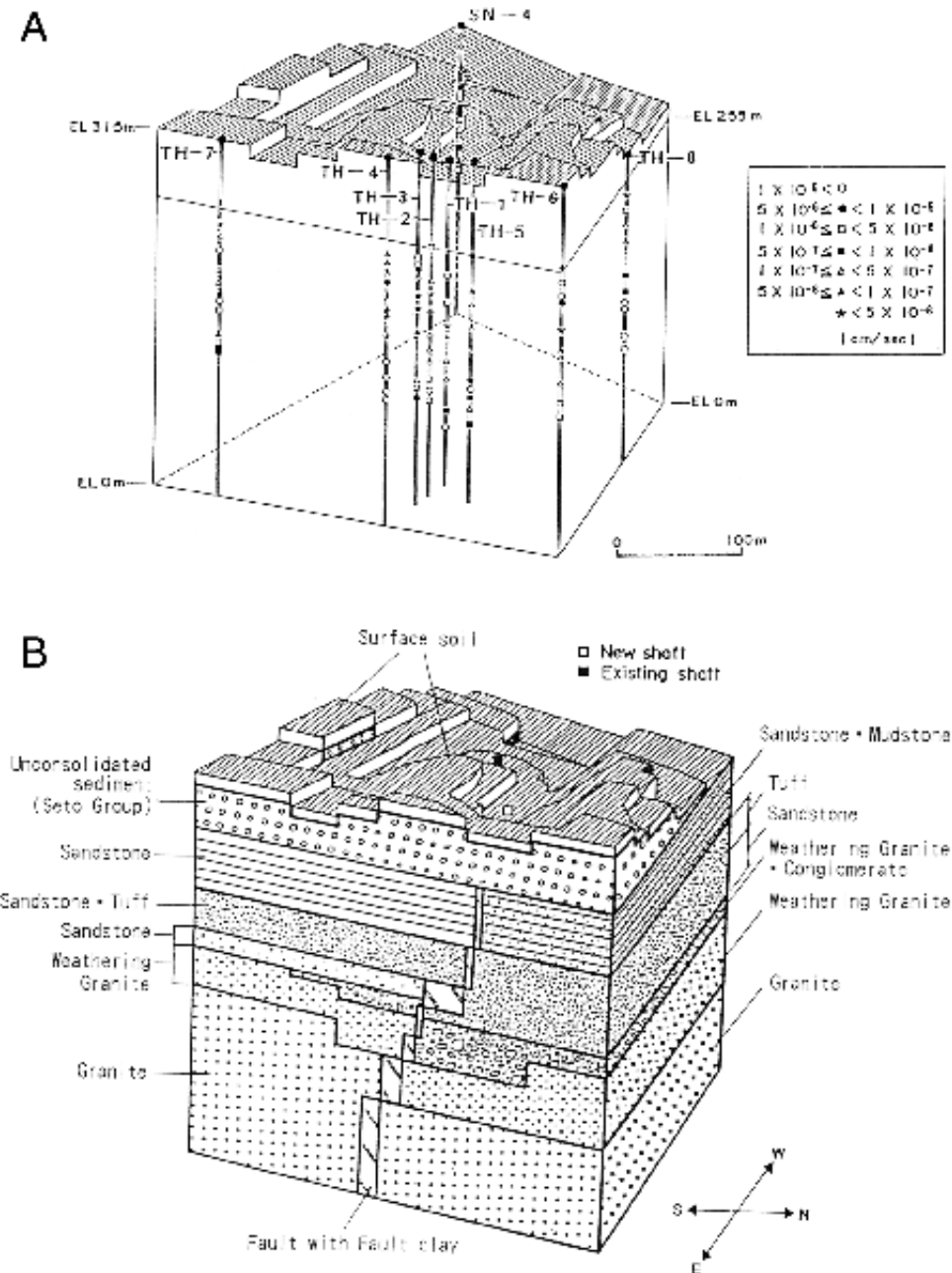


Figure 15.2 A - Hydraulic conductivity distribution, and B - hydrogeological model for the Tono region.

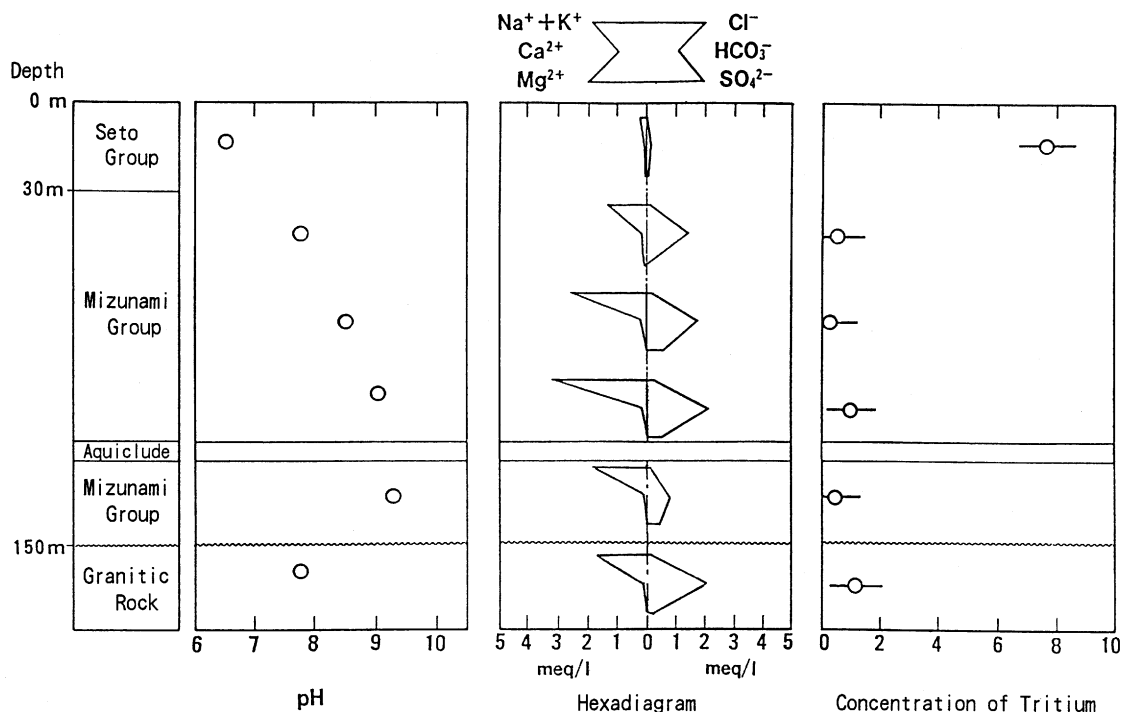


Figure 15.3. Groundwater pH, chemistry and tritium concentration for the Tono region (Major solution components are presented on a hexadiagram).

For a three-dimensional analysis of groundwater flow taking the example of the Tono region, piezometric heads are almost hydrostatic except near the surface. The hydraulic gradient is below 0.04 for areas deeper than 500 m underground. The procedure for future research on groundwater flow will be to obtain hydraulic data for depths down to 1,000 m underground, to improve methods for analyzing groundwater flow and to develop suitable investigation methods for a given region.

Geochemical studies aim to determine the age and origin of groundwater and the distribution of geochemical characteristics and to confirm the relevance of the model of the geochemical evolution of groundwater. For this purpose, sampling and analysis of groundwaters from boreholes is being carried out. Groundwaters in sedimentary rocks are mostly the Na-HCO_3 type, and the pH value moves from neutral to alkaline as depth increases (Fig 15.3). A comparative analysis of oxygen and hydrogen stable isotopes confirms the theory of precipitation as the origin of the groundwater.

Radiocarbon dating reveals the groundwater at the base of the sedimentary formations to be at least in excess of 104 years old. The figures for pH, redox potential and concentration of chemical components obtained from a geochemical equilibrium model and from actual mea-

surements in the region agree well with one another. Future tasks are to accumulate geochemical data down to a depth of 1,000 m and to study the geochemical evolution of deep groundwaters, also for granitic rocks (Yamakawa, 1991; Yoshida, et. al., 1994).

To examine solute migration in the deep geological environment, the Tono uranium deposit and its surrounding area are being studied as a natural analogue for migration and immobilization of material within a geological formation. Studies are underway on the environmental conditions for generation and preservation of uranium deposits and on the migration and retardation of natural series nuclides by groundwater flow. Studies so far show that uranium is immobilized in a reducing environment, that the migration and concentration of uranium depends not only on the mineralogy and chemistry of the rocks but also on groundwater flow, and that the uranium found in the ore deposit has not migrated significantly over the past 10^5 years. Future studies should clarify the route of groundwater flow and its relationship with migration of natural series nuclides, and also quantify migration and advance modeling of sorption phenomena.

To ascertain the influence of excavation on the rock formations surrounding a gallery, a series of studies are

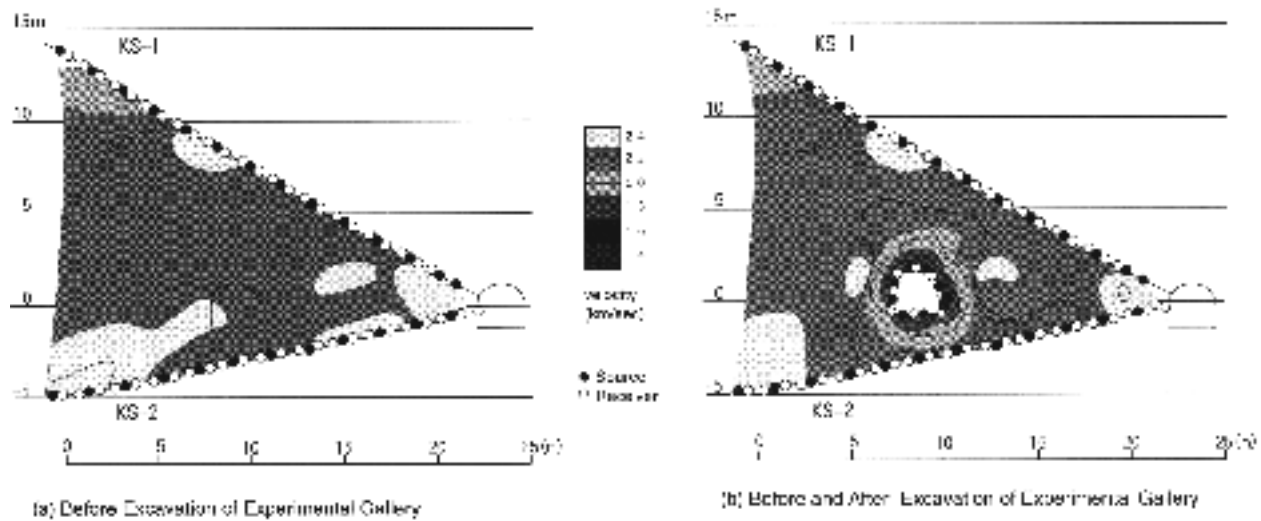


Figure 15.4. Experiment on excavation effects at the Tono Mine.

being conducted in which the original condition of the bedrock is assessed before excavation, followed by prediction of the effect of excavation and, finally, by actual measurement of the effects of excavation (Fig. 15.4). In a study of excavation effects, a shaft with a 6 m inner diameter and 150 m deep has been observed for approximately the past four years. Observations indicate that the “excavation disturbed zone” created by blasting the bedrock extended about 1 m from the shaft wall, while changes in pore pressure extended to a radius of approximately 100 m from the shaft. The next step is to ascertain the effects on different rock types and of varying methods of excavation, as well as to improve the techniques employed in measurement and analysis. It is also necessary to continue monitoring over an extensive period in order to understand the long-term impact on bedrock deformation and hydrology, etc (Sato, et. al., 1995).

15.4.2 Surveys Conducted at Kamaishi Mine

The Kamaishi Mine is an iron and copper mine with granite as the parent rock; it is situated near Kamaishi City in Iwate Prefecture. PNC has been conducting investigations in the Kurihashi granitic diorite since 1988, in a gallery located 550 m above sea level (approximately 300 m below ground surface). In 1993, a second phase was launched for a five-year period in a gallery 250 m above sea level (approximately 700 m below ground surface). The research includes assessment of geological characteristics deep underground, appraisal of the extent of the excavation disturbed zone in the bedrock, hydraulic and migration tests in crys-

talline rock, testing of engineered barriers and seismic surveys (Fig. 15.5) (Takeda and Osawa, 1993).

In the first five years, the aim was to collect data on the distribution of various characteristics and phenomena occurring in the geological environment. At the same time, the appropriateness of investigation techniques was also tested. Surveys conducted included investigations of fractures in gallery walls and boreholes, physical surveys to ascertain the distribution of fractures, hydrogeological research to assess the permeability of the bedrock, groundwater flow and its modeling, geochemical research to determine the origin, age, chemical evolution, etc., of groundwater, bedrock dynamics to test the effects of gallery excavation, seismic research, and research on engineered barriers.

These studies contribute to improving the understanding of physical properties such as the strength of the Kurihashi granitic diorite, initial stress conditions, the permeability of the bedrock, channeling phenomena whereby groundwater tends to flow along distinct pathways within a fracture, geochemical properties of groundwater deep underground and *in-situ* swelling of bentonite clay as a backfill in bedrock. Studies conducted on the effect of gallery excavation on the geological environment showed that any change in the permeability and deformation of the bedrock occurred within a radius of 1 m from the gallery wall.

Through these studies, it is possible to ascertain the effectiveness of techniques for modeling groundwater flow near the gallery and the deformation behavior of

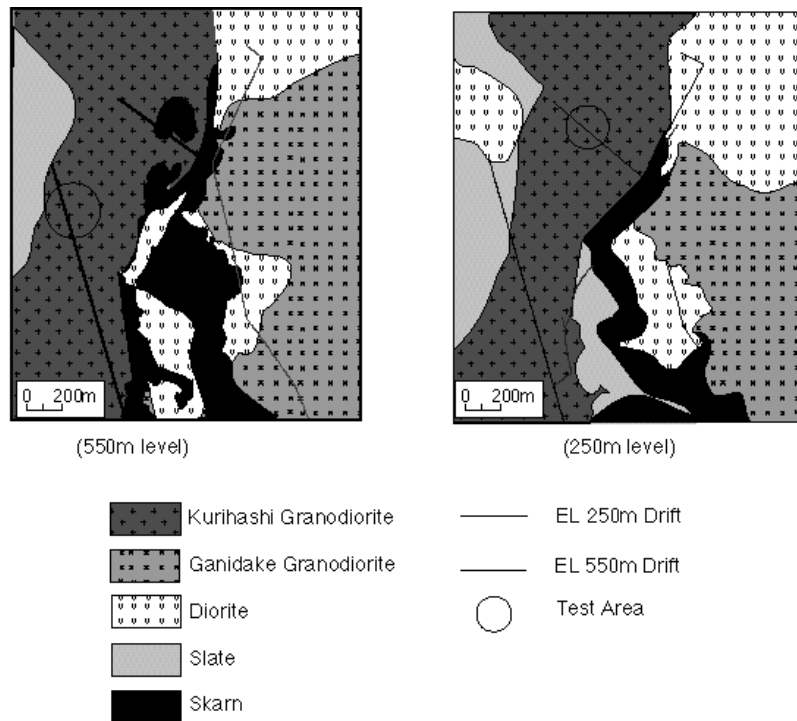


Figure 15.5. Geological map of the *in-situ* experimental site at the Kamaishi Mine.

adjacent bedrock due to the gallery excavation. They also allow validation of radar and resistivity tomography methodology, the derived model of fracture distribution and the technique used for permeability determination.

Seismometers were placed in galleries at different depths to observe seismic-related characteristics; a continuous analysis of pore pressure and the chemical properties of groundwater was also carried out. The results indicate that, for the majority of earthquakes, the rate of acceleration several hundred meters below surface is about half that at the ground surface (Fig. 15.6). Long-term observation of pore pressure and chemical properties of groundwater showed a temporary change at the time of earthquakes, but this was within the range of seasonal fluctuations.

In 1993, a new five-year project was launched to investigate the different characteristics of the deep geological environment and to obtain a more detailed understanding of the range of effects caused by gallery excavation. The work covers geochemical changes occurring within nearby bedrock, the distribution of fractures in the bedrock and galleries, solute migration and water flow, thermal, hydraulic and dynamic interactions between bentonite clay and surrounding bedrock and groundwa-

ter, the impact of earthquakes on groundwater flow, and the decrease of earthquake motion with depth.

So far, the studies have shed light on the initial stress conditions at various depths (galleries at 250 m level and 550 m level), the distribution of fractures and microcracks from the viewpoint of mass transport and the redox conditions of groundwater in the vicinity of

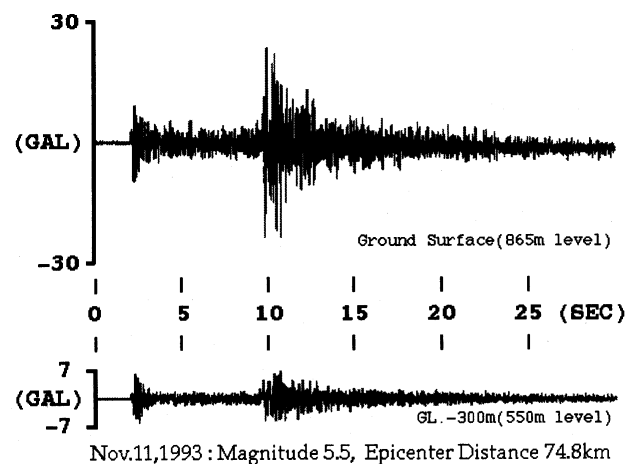


Figure 15.6. Seismic observations at ground surface and underground at the Kamaishi Mine.

galleries.

15.4.3 Development of Techniques for Investigating Deep Geological Environment

In order to make quantitative measurements of hydraulic parameters deep underground, a hydraulic measurement device designed for conditions of slow water pressure build-up has been developed for application in low permeability bedrock. An *in-situ* measurement device has already been constructed for use at depths down to 500 m and in the order of 10^{-11} m/s for the hydraulic conductivity. Other equipment developed allows a continuous *in-situ* measurement of parameters such as redox potential, pH and dissolved oxygen concentration. With the development of a packer-system in a pressured groundwater sampling device, which is gas-tight, it is now possible to obtain groundwater samples without disturbing their original condition within the rock formation. A new device was completed in 1994; it can be used down to a depth of 1,000 m and is in the process of being tested. Efforts have also been devoted to developing an evapotranspiration device for measuring the distribution of influx volumes from gallery walls and a sinusoidal, crosshole experimental device for use in a single fracture near the gallery wall.

When gathering data in the deep geological environment, it is desirable to do so without disturbing the natural conditions, so as to fully preserve the fractures within the bedrock, the geological structure and hydraulic characteristics. As a consequence, the development and testing of resistivity and seismic tomography are presently underway. Furthermore, a radar technique is being developed, which uses multiple boreholes in order to determine precise fracture zone locations and their extent.

It is also important to improve surface-based methods for predicting conditions in the deep geological environment; the results can then be confirmed using data obtained after excavation of galleries. Research in this area is being carried out jointly by SKB and PNC.

15.4.4 Research on the Long-Term Stability of the Geological Environment

In the first technological report (PNC's Heisei 3 Report), natural phenomena with a potential influence on the geological environment were summarized, suggesting the existence of regionality and regularity in

these phenomena. They include earthquake and fault activity, volcanic activity, uplift and denudation, climatic fluctuation and sea-level change. In view of the importance of understanding and predicting the influence of these phenomena on the geological environment, surveys are being conducted of relevant literature published in Japan and abroad (Shimizu, et. al., 1992).

Literature surveys and analyses are performed to first clarify the history of individual natural phenomena. The next step is to conduct research on the nature and scale of the impact of such phenomena on the geological environment and to establish a method for defining a realistic range of fluctuation for the predicted influence of these phenomena.

Regarding fault activity, attention is focused on the possibility of the formation of new faults, by observing the fluctuations in time and space and the locations of fault activity. A method for ascertaining the hydraulic and geochemical fluctuations in groundwater is being considered in order to provide an understanding of the range of influence of fault activity on the nearby geological environment.

To predict the range of variation in uplift and subsidence, it is necessary to have accurate knowledge of past data and an understanding of crustal movements in Japan; a systematic compilation is therefore being made of relevant geomorphological data. To estimate topographic and decreases in the thickness of geological formations, which accompany uplift and subsidence, modeling of denudation and future topographic changes is also necessary.

As for volcanic activity, the characteristics and regionality of Quaternary volcanic activity should be ascertained; the locations of activity as well as the relationship between geological structure, stress fields and plate distribution should also be clarified in order to substantiate the assumption that the region of volcanic activity will not change in the future. Studies should be able to determine the range and scale of thermal impact and its influence on the geochemical characteristics and flow of groundwater.

Studies should be carried out to assess the scale and regularity of climatic and sea-level changes on a global scale.

15.5 CONCLUSIONS

Any discussion of the geological environment of Japan within the context of geological disposal programs requires the development of transparent and logical analytical methods and a systematic accumulation of reliable data. It is also important to make maximum use of existing information. Advances in a new field of research and development, as in the case of this report, should be pursued with the support of public understanding and participation, from the beginning, of experts from all related areas of study; this ensures transparency and steady progress. By way of recognizing the importance of obtaining the consensus of experts from various fields on the overall progress and direction of R & D programs, as well as on individual studies, projects are pursued with constant referral to various commissions.

Regarding sites for research on the deep geological environment, the Atomic Energy Commission of Japan has indicated the desirability of having multiple facilities in view of the wide range of geological features in Japan; this is stated in the "Long-Term Program for Research, Development and Utilization of Nuclear Energy." There is also a clear distinction between plans for an underground research facility and plans for geological disposal. PNC is also aware of the importance of carrying out research, not only in existing galleries, but also in geological environments with undisturbed conditions. It is also important to verify predictive surveys made from the ground surface, following actual excavation of galleries. A research facility which would allow such activities to be pursued is of utmost importance and PNC is devoting considerable efforts toward construction of such a facility as soon as possible.

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